

APPLICATION FOR PATENT

Inventors: Yutaka Takano  
Masato Ikeda  
Tatsuro Fujio

Citizens of: Japan

Post Office  
Addresses:

c/o Technical Research Laboratories,  
KYOWA HAKKO KOGYO CO., LTD.  
1-1, Kyowa-cho, Hofu-shi, Yamaguchi  
747-8522 Japan

c/o Technical Research Laboratories,  
KYOWA HAKKO KOGYO CO., LTD.  
1-1, Kyowa-cho, Hofu-shi, Yamaguchi  
747-8522 Japan

c/o Head Office, KYOWA HAKKO KOGYO  
CO., LTD.  
6-1, Ohtemachi 1-chome, Chiyoda-ku,  
Tokyo 100-8185 Japan

Title: Process for Producing Purine Nucleotides

## PROCESS FOR PRODUCING PURINE NUCLEOTIDES

Background of the Invention

The present invention relates to a process for producing  
5 purine nucleotides which are in great demand as seasoning  
agents, and to microorganisms useful in said process.

5'-Guanylic acid (hereinafter abbreviated as GMP) and  
5'-inosinic acid (hereinafter abbreviated as IMP) are purine  
nucleotides which exhibit a strong flavor-enhancing activity  
10 and are widely used as chemical seasoning components.

Some processes are known for producing these  
flavor-enhancing nucleotides: for example, a process which  
comprises hydrolyzing RNA extracted from yeast cells with  
ribonuclease P1 and then isolating and purifying the desired  
15 5'-nucleotide [Food Technol., 18, 287 (1964)]; a process of  
directly producing IMP by fermentation using a microorganism  
having the ability to produce IMP [Agricultural and Biological  
Chemistry, 46, 2257 (1982)]; a process which comprises  
converting nucleosides such as inosine and guanosine into  
20 nucleotides by chemical phosphorylation [Bulletin of the  
Chemical Society of Japan, 42, 3505 (1969)]; a process which  
comprises producing 5-amino-4-imidazolecarboxamide riboside  
(hereinafter abbreviated as AICAR) by fermentation using a  
mutant of Bacillus megaterium, and then producing a nucleotide  
25 from AICAR by chemical synthesis [Biotechnol. Bioeng., 2, 329  
(1967); J. Org. Chem., 32, 1825 (1967)]; and a process which  
comprises culturing a mutant of Corynebacterium ammoniagenes  
which produces 5'-xanthylic acid (hereinafter abbreviated as  
XMP) in a medium to form and accumulate XMP, culturing  
30 Escherichia coli increased in the activity of XMP aminase (also  
known as GMP synthetase) obtained by self-cloning, and then  
producing GMP from XMP by enzyme reaction using the cultured  
E. coli cells as an enzyme source [Biosci. Biotech. Biochem.,  
61, 840 (1997); Japanese Published Unexamined Patent  
35 Application No. 233798/88].

To sum up, processes for producing flavor-enhancing

nucleotides so far developed can be classified into the following three groups in principle [Shoichi Takao, et al. (ed.), Oyo Biseibutsugaku (Applied Microbiology), Buneido Shuppan (1996)]:

- 5 (1) a method in which yeast RNA is degraded with a microorganism-derived enzyme or chemically (the RNA degradation method),
- (2) a method of directly producing a nucleotide by culturing a mutant of a microorganism in a medium containing sugars,  
10 a nitrogen source and a phosphoric acid source (the direct fermentation method), and
- (3) a method which comprises producing an intermediate for the nucleotide synthesis by fermentation, and converting said intermediate into a nucleotide chemically or  
15 enzymatically (the method which is a combination of fermentation and chemical synthesis or enzymatic conversion).

In the RNA degradation method (method (1) above), pyrimidine nucleotides are also produced in almost the same  
20 amounts as flavor-enhancing purine nucleotides, and so the purification step necessarily becomes complicated. In the direct fermentation method (method (2) above), it is not easy to breed a microorganism which can extracellularly form and accumulate a considerable amount of nucleotides because of  
25 low membrane permeability of nucleotides, and thus it is difficult to obtain an economically satisfactory productivity of nucleotides. Specifically, there has not been known a process for direct production of GMP so far. However, it is known that XMP can be exceptionally formed and accumulated  
30 in considerable amounts [Shoichi Takao, et al. (ed.), Oyo Biseibutsugaku (Applied Microbiology), Buneido Shuppan (1996)]. At present, as an economically advantageous method for producing flavor-enhancing nucleotides, the combination method of fermentation and chemical synthesis or enzymatic  
35 conversion (method (3)) is widely employed for industrial production of the nucleotides.

In this combination method, one of the points for the improvement of the entire productivity is to enhance the yield of an intermediate for the nucleotide synthesis in the fermentation step (the first stage of the process). To this end, a large number of microorganisms having high productivity of XMP, guanosine or inosine have been bred [Agricultural and Biological Chemistry, 42, 399 (1978); Agricultural and Biological Chemistry, 43, 1739 (1979); Agricultural and Biological Chemistry, 46, 2347 (1982)].

There have also been developed various methods of chemical or enzymatic conversion of an intermediate into a nucleotide (the second stage of the process). As a chemical method, site-specific phosphorylation reaction (nucleoside  $\rightarrow$  5'-nucleotide) [Bulletin of the Chemical Society of Japan, 42, 3505 (1969)] is industrially used. However, the chemical phosphorylation reaction requires the intermediate step to purify a nucleoside as a phosphate group acceptor to the necessary extent and also requires the use of a chemical reaction vessel in addition to a fermentor used for the fermentation step. Therefore, the enzymatic methods using aminase or phosphorylase attract attention and have been studied. As for the amination, a method using XMP aminase is known [Shoichi Takao, et al. (ed.), Oyo Biseibutsugaku (Applied Microbiology), Buneido Shuppan (1996)].

Sub-B1 As for the phosphorylation, methods using phosphotransferase, kinase and phosphatase are known. In particular, the reaction utilizing kinase or phosphatase has been studied as an efficient method. For example, there have been developed a process for producing a 5'-nucleotide by the use of an Escherichia coli strain carrying a gene encoding inosine-guanosine kinase of Escherichia coli (W091/08286), a process for producing a 5'-nucleotide by the use of a Corynebacterium ammoniagenes strain carrying a gene encoding inosine-guanosine kinase of Exiguobacterium acetylicum (W096/30501), and a process for producing a 5'-nucleotide by the use of an Escherichia coli strain carrying a gene prepared

by imparting a random mutation to the phosphatase gene of Morganella morganii (Japanese Published Unexamined Patent Application No. 37785/97, Japanese Published Unexamined Patent Application No. 201481/98).

5 As the phosphate group donor, various compounds have been studied. For example, methods using the following substances are known: P-nitrophenyl phosphate (Japanese Published Examined Patent Application No. 2985/64), inorganic phosphoric acid (Japanese Published Examined Patent  
10 Application No. 1186/67, Japanese Published Examined Patent Application No. 44350/74), polyphosphoric acid (Japanese Published Unexamined Patent Application No. 56390/78), acetyl phosphate (Japanese Published Unexamined Patent Application No. 82098/81), ATP (Japanese Published Unexamined Patent  
15 Application No. 230094/88), polyphosphoric acid, phenyl phosphate and carbamyl phosphate (Japanese Published Unexamined Patent Application No. 37785/97), and pyrophosphoric acid (Japanese Published Unexamined Patent Application No. 37785/97, Japanese Published Unexamined  
20 Patent Application No. 201481/98).

However, these methods are not industrially advantageous for the reasons that the substrates to be used are expensive or unstable, the purification steps become complicated because of formation of reaction by-products, etc.  
25 As a practical method to meet the economical need, the nucleotide production system by the use of the ATP-regenerating system has been developed. In this system, a microorganism regenerates ATP from AMP or ADP using inorganic phosphoric acid in the course of carbohydrate metabolism. For  
30 example, a method has been proposed in which the activity to biosynthesize ATP by metabolizing glucose possessed by an XMP-producing microorganism is used as the ATP-regenerating system. There are publications teaching a method for producing GMP using inexpensive glucose and inorganic  
35 phosphoric acid as ATP-regenerating substrates instead of ATP by coupling the above ATP-regenerating system with the XMP

aminase activity of a microorganism having the ability to form GMP from XMP and ATP [Biosci. Biotech. Biochem., 61, 840 (1997)], and a similar method using inosine kinase as an enzyme to produce IMP (Japanese Published Unexamined Patent

5 Application No. 230094/88).

Two kinds of microorganisms are used in a process for producing GMP or IMP which comprises the fermentation step to produce XMP, guanosine or inosine by direct fermentation and the reaction step to enzymatically convert the  
10 fermentation product into GMP or IMP.

That is, in the fermentation step which is the first stage of the process, a mutant bred as an XMP-, guanosine- or inosine-producing microorganism (a producing microorganism) is used. In the reaction step of amination or  
15 phosphorylation which is the second stage of the process, a microorganism carrying a highly expressed gene encoding a protein having XMP aminase activity or inosine-guanosine kinase activity (a converting microorganism) is used.

ATP which is necessary in the reaction of the second stage is regenerated by the ATP-regenerating activity of not only the converting microorganism used in the second stage, but also the producing microorganism used in the first stage.  
20

Thus, the reaction step of the second stage is a system coupling the XMP aminase activity or the inosine-guanosine  
25 kinase activity and the ATP-regenerating activity of two microorganisms.

The outline of the whole process is described below.

First, a producing microorganism is cultured in a medium mainly comprising sugars and nitrogen sources in a large  
30 fermentor to form and accumulate XMP, guanosine or inosine. Separately, a converting microorganism is cultured in a small fermentor. When the fermentation of the first stage is completed, the separately cultured converting microorganism is added to the large fermentor to carry out phosphorylation  
35 reaction or amination reaction in the presence of an inexpensive energy donor and a phosphate group donor.

The above process utilizing the enzyme reaction is advantageous compared with the chemical phosphorylation method as described above. However, it is still not entirely satisfactory in respect of efficiency because a small fermentor is necessary for culturing a converting microorganism, and the amount of the medium must be reduced at the fermentation step of the first stage in view of the addition of a converting microorganism, which lowers the amount of the desired nucleotide obtained per batch.

An object of the present invention is to develop a process for producing a purine nucleotide efficiently in one fermentor.

#### Summary of the Invention

The present inventors pursued the possibility of developing a more excellent process for producing a purine nucleotide in which fermentation to produce a precursor of the nucleotide and reaction to convert said precursor into the nucleotide can be carried out successively using only one microorganism in one fermentor, by introducing a gene of an enzyme capable of synthesizing the purine nucleotide from its precursor into a fermentation microorganism having the ability to produce the precursor of the purine nucleotide and by regulating the expression of the gene in both of the fermentation step and the reaction step. As a result of intensive studies in the pursuit of this possibility, the present invention has been completed.

The present invention relates to the following (1)-(19).

- (1) A process for producing a purine nucleotide which comprises: culturing in a medium a microorganism having the ability to produce a precursor of the purine nucleotide and carrying an introduced DNA which can ~~induce~~ <sup>upon induction</sup> ~~and~~ express an enzyme capable of synthesizing the purine nucleotide from said precursor; allowing said precursor of the purine nucleotide to accumulate in the culture;

<sup>the expression of</sup>  
 inducing ~~and expressing~~ the enzyme capable of <sup>And expressing said enzyme</sup>  
 synthesizing the purine nucleotide from said precursor;  
 allowing the purine nucleotide formed from said precursor  
 to accumulate in said culture; and then recovering said  
 purine nucleotide therefrom.

- (2) The process according to the above (1), wherein the precursor of the purine nucleotide is 5'-xanthylic acid, the enzyme capable of synthesizing the purine nucleotide from said precursor is 5'-xanthylic acid aminase, and the purine nucleotide is 5'-guanylic acid.
- (3) The process according to the above (1), wherein the precursor of the purine nucleotide is guanosine, the enzyme capable of synthesizing the purine nucleotide from said precursor is inosine-guanosine kinase or phosphatase, and the purine nucleotide is 5'-guanylic acid.
- (4) The process according to the above (1), wherein the precursor of the purine nucleotide is inosine, the enzyme capable of synthesizing the purine nucleotide from said precursor is inosine-guanosine kinase or phosphatase, and the purine nucleotide is 5'-inosinic acid.
- (5) The process according to the above (1), wherein the microorganism belongs to the genus selected from the group consisting of Corynebacterium, Escherichia and Bacillus.
- (6) The process according to the above (1), wherein the microorganism is Corynebacterium ammoniagenes.
- (7) The process according to the above (1), which is characterized in that <sup>the expression of</sup> the enzyme capable of synthesizing the purine nucleotide is induced ~~and expressed~~ by the change of condition selected from the group consisting of rise in temperature, rise in pH and rise in osmotic pressure, or by the change of the carbon source from sugars to non-sugars.
- (8) The process according to the above (7), wherein the non-sugar carbon source is acetic acid or acetate.
- (9) A DNA which can ~~induce and~~ express an enzyme capable of

synthesizing a purine nucleotide from its precursor. <sup>upon induction</sup>

- (10) The DNA according to the above (9), which can ~~induce and~~ <sup>upon induction</sup> express the enzyme capable of synthesizing the purine nucleotide by the change of condition selected from the group consisting of rise in temperature, rise in pH and rise in osmotic pressure, or by the change of the carbon source from sugars to non-sugars.
- (11) The DNA according to the above (10), wherein the non-sugar carbon source is acetic acid or acetate.
- (12) The DNA according to the above (9) or (10), which is pLAC857 or pIGK2.
- (13) A microorganism having the ability to produce a precursor of a purine nucleotide and carrying an introduced DNA which can ~~induce and~~ <sup>upon induction</sup> express an enzyme capable of synthesizing the purine nucleotide from said precursor.
- (14) The microorganism according to the above (13), wherein the precursor of the purine nucleotide is 5'-xanthylic acid, the enzyme capable of synthesizing the purine nucleotide from said precursor is 5'-xanthylic acid aminase, and the purine nucleotide is 5'-guanylic acid.
- (15) The microorganism according to the above (13), wherein the precursor of the purine nucleotide is guanosine, the enzyme capable of synthesizing the purine nucleotide from said precursor is inosine-guanosine kinase or phosphatase, and the purine nucleotide is 5'-guanylic acid.
- (16) The microorganism according to the above (13), wherein the precursor of the purine nucleotide is inosine, the enzyme capable of synthesizing the purine nucleotide from said precursor is inosine-guanosine kinase or phosphatase, and the purine nucleotide is 5'-inosinic acid.
- (17) The microorganism according to the above (13), which belongs to the genus selected from the group consisting of Corynebacterium, Escherichia and Bacillus.
- (18) The microorganism according to the above (13), which is Corynebacterium ammoniagenes.
- (19) The microorganism according to the above (18), which is

See  
B3

Corynebacterium ammoniagenes ATCC 6872/pLAC857 (FERM BP-6639) or Corynebacterium ammoniagenes ATCC 6872/pIGK2 (FERM BP-6638).

## 5 Brief Description of the Drawings

Fig. 1 is a drawing showing the structure of plasmid pLAC857.

Fig. 2 is a drawing showing the structure of plasmid pGUA2.

10 Fig. 3 is a drawing showing the structure of plasmid pIGK2.

The symbols used in the drawings represent the following.

P<sub>L</sub>: P<sub>L</sub> promoter

15 guaA: XMP aminase gene derived from Escherichia coli

C.glt ORI: Replication origin of Corynebacterium glutamicum

Spc<sup>r</sup>: Spectinomycin resistance gene

cI857: Temperature sensitive repressor gene

20 P<sub>ICL</sub>: Expression-regulating region of the isocitrate lyase gene derived from Corynebacterium glutamicum

T<sub>ICL</sub>: Terminator of the isocitrate lyase gene derived from Corynebacterium glutamicum

igk: Inosine-guanosine kinase gene derived from Escherichia coli

25 Km<sup>r</sup>: Kanamycin resistance gene

Ap<sup>r</sup>: Ampicillin resistance gene

E.coli ORI: Replication origin of Escherichia coli

## Detailed Description of the Invention

30 The present invention provides a process wherein the fermentation step to produce a precursor of a purine nucleotide by direct fermentation and the reaction step to enzymatically convert the precursor produced in said fermentation step into the purine nucleotide are carried out successively using a  
35 single microorganism in one fermentor.

The following three requirements have been found to be

important for the establishment of said process.

The first requirement is that in the fermentation step to produce the precursor of the purine nucleotide by direct fermentation, the expression of a gene encoding an enzyme  
5 capable of synthesizing the purine nucleotide from its precursor needs to be suppressed to such a level that the fermentation is not substantially disturbed.

If the expression of said enzyme can not be suppressed, the purine nucleotide is formed and accumulated  
10 intracellularly by the activity of said enzyme during the fermentation and the fermentation yield of the purine nucleotide falls for the following reasons.

When GMP is accumulated as the purine nucleotide, the feedback inhibition of the key enzyme in the purine  
15 biosynthetic pathway is induced, whereby the production of XMP stops. When IMP is accumulated, a futile cycle is formed with inosine formation, causing waste of ATP. Thus, intracellular formation and accumulation of the purine nucleotide lowers the fermentation yield, which leads to an  
20 economical disadvantage.

The second requirement is that in the reaction step to synthesize the purine nucleotide from its precursor, it is needed to sufficiently induce the activity of the enzyme capable of synthesizing the purine nucleotide from its  
25 precursor.

The third requirement is that a producing microorganism which has undergone the fermentation and the induction treatment needs to retain a sufficient ATP-regenerating activity and the phosphorylation or amination activity for  
30 the conversion reaction, and these activities need to fully function in the reaction step to synthesize the purine nucleotide from its precursor.

The microorganism to be used in the present invention may be a wild strain, a mutant, a fused cell line, a  
35 transductant or a recombinant strain obtained by means of recombinant DNA techniques, so long as it has the ability to

produce a precursor of a purine nucleotide and has the ATP-regenerating activity. Preferred microorganisms include those belonging to the genus Corynebacterium, Escherichia or Bacillus, which are useful for nucleic acid fermentation and amino acid fermentation. Particularly preferred is Corynebacterium ammoniagenes which has a strong ATP-regenerating activity.

The precursors of purine nucleotides include XMP, guanosine, inosine, adenosine, etc.

The ATP-regenerating activity refers to the activity to regenerate ATP from AMP or ADP using inorganic phosphoric acid in the process where a microorganism metabolizes sugars as energy donor substrates. This ATP-regenerating system is a part of the carbohydrate metabolism system and the energy metabolism system such as the glycolytic pathway, the TCA cycle and the electron transport system, and almost all microorganisms have this activity.

Specific examples of the microorganisms to be used in the present invention include the following strains and mutants derived therefrom.

Corynebacterium ammoniagenes ATCC 6872  
Corynebacterium ammoniagenes ATCC 21295  
Corynebacterium ammoniagenes ATCC 21477  
Corynebacterium glutamicum ATCC 13032  
Corynebacterium glutamicum ATCC 14067  
Corynebacterium glutamicum ATCC 13869  
Escherichia coli ATCC 14948  
Escherichia coli ATCC 11303  
Escherichia coli ATCC 9637  
Bacillus subtilis ATCC 14618

*Sub B4* As the enzyme capable of synthesizing a purine nucleotide from its precursor to be used in the present invention, any enzyme capable of synthesizing a purine nucleotide from its precursor can be used, and suitable examples include XMP aminase, inosine-guanosine kinase,

phosphatase and adenylate kinase.

Examples of the DNAs encoding the above enzymes are given below.

Genes encoding XMP aminase include those derived from  
 5 Escherichia coli [Nucleic Acids Res., 13, 1303 (1985)],  
Bacillus subtilis [Nucleic Acids Res., 18, 6710 (1990)],  
Corynebacterium ammoniagenes (Genbank accession no.  
 g2765074), etc.

Genes encoding inosine-guanosine kinase include those  
 10 derived from Escherichia coli (W091/08286), Exiguobacterium  
acetylicum (W096/30501), etc.

*See B5* Genes encoding phosphatase include those derived from  
~~Morganella morganii~~ (Japanese Published Unexamined Patent  
 Application No. 37785/97, Japanese Published Unexamined  
 15 Patent Application No. 201481/98), etc.

Genes encoding adenylate kinase include that derived  
 from Saccharomyces cerevisiae [J. Biol. Chem., 263, 19468  
 (1988)].

The genes encoding the enzymes capable of synthesizing  
 20 a purine nucleotide from its precursor can be obtained by a  
 known method.

For example, in the case of the gene encoding XMP aminase,  
 primers are synthesized based on the sequences at both ends  
 of the sequence of an XMP aminase structural gene, and the  
 25 XMP aminase structural gene can be obtained by the polymerase  
 chain reaction method (PCR method) using the prepared primers  
 and the Escherichia coli chromosomal DNA, the Bacillus  
subtilis chromosomal DNA or the Corynebacterium ammoniagenes  
 chromosomal DNA.

*See B6* In the case of the gene encoding inosine-guanosine  
 kinase, primers are synthesized based on the sequences at both  
 ends of the sequence of an inosine-guanosine kinase structural  
 gene, and the inosine-guanosine kinase structural gene can  
 be obtained by the PCR method using the prepared primers and  
 35 the Escherichia coli chromosomal DNA or the Exiguobacterium  
acetylicum chromosomal DNA. Similarly, by the use of the PCR

method, a phosphatase structural gene can be obtained from the Morganella morganii chromosomal DNA and an adenylate kinase structural gene can be obtained from the Saccharomyces cerevisiae chromosomal DNA.

5       The thus obtained gene encoding the enzyme capable of synthesizing a purine nucleotide from its precursor is inserted into an appropriate inducible-expression vector so that the gene is under the control of the transcription and translation signal capable of regulating its ~~induction and~~  
10      expression, whereby a recombinant plasmid which can regulate the expression of said gene can be obtained.

15       There is no specific restriction as to the inducible-expression vector, so long as it is replicable in a microorganism to be used and fulfills the following three conditions.

20       First, the expression of the gene encoding the enzyme capable of synthesizing a purine nucleotide from its precursor can be repressed to a level where fermentation is not substantially disturbed in the fermentation step to produce the precursor of the purine nucleotide by direct fermentation.

25       Secondly, the activity of the enzyme capable of synthesizing the purine nucleotide from its precursor is sufficiently induced by the induction treatment to be carried out prior to the reaction step to synthesize the purine nucleotide from its precursor.

30       Thirdly, said induction method is a method which allows a producing microorganism to retain a sufficient ATP-regenerating activity and the converting activity after the induction treatment.

35       Examples of the vectors which fulfill the above three conditions include pPAC31 which contains the  $P_L$  promoter/cI857 repressor gene and is induced at a high temperature (WO98/12343), pBB1 which contains the lac promoter/lacIts repressor gene and is induced at a high temperature [Gene, 70, 415 (1988)], pRK248cIts which contains the  $P_L$  promoter/cI857 repressor gene and is induced at a high pH [Gene,

97, 125 (1991)], pOSEX2 which contains the proU expression-regulating region and is induced under a high osmotic pressure [Gene, 151, 137 (1994)], pTrc99A which contains the trc promoter/lacI<sup>q</sup> repressor gene and is induced with isopropyl- $\beta$ -D-thiogalactoside (IPTG) [Gene, 69, 301 (1988)], pAL9181 which contains the araBAD promoter/araC repressor gene and is induced with L-arabinose [Appl. Microbiol. Biotechnol., 37, 205 (1992)] and vectors induced by changing the carbon source from sugars to non-sugars. These vectors are inducible-expression vectors constructed for Escherichia coli.

Further, vectors obtained by modifying the transcription-translation signal region related to the regulation of the expression in the above inducible-expression vectors by mutation techniques or recombinant DNA techniques can be used as well.

When these known inducible-expression vectors or further improved vectors are used in host cells other than Escherichia coli, a replication origin which functions in the host is inserted therein. For example, when Corynebacterium ammoniagenes is employed as a host, a replication origin of a plasmid derived from Corynebacterium glutamicum which functions in Corynebacterium ammoniagenes or the like is inserted into said vector.

The plasmids derived from Corynebacterium glutamicum include pCG1 (Japanese Published Unexamined Patent Application No. 134500/82), pCG2 (Japanese Published Unexamined Patent Application No. 35197/83), pCG4 (Japanese Published Unexamined Patent Application No. 183799/82), PAM330 (Japanese Published Unexamined Patent Application No. 67699/83), and pAG1, pAG3, pAG14 and pAG50 (Japanese Published Unexamined Patent Application No. 166890/87).

The preferred vectors functioning in Corynebacterium include a plasmid vector capable of being induced by raising the temperature which is prepared by ligating the P<sub>L</sub> promoter/cI857 gene carried by pPAC31 which is a vector induced

at a high temperature in Escherichia coli with a vector autonomously replicable in Corynebacterium, vector pCEX2 capable of being induced with a non-sugar carbon source such as acetic acid (Japanese Published Unexamined Patent Application No. 224259/91), etc.

On the other hand, when the transcription-translation signal related to the regulation of gene expression in the inducible-expression vectors does not function in a microorganism to be used, or when it functions but the above three requirements are not sufficiently fulfilled, it is necessary to improve said transcription-translation signal region by mutation techniques or recombinant DNA techniques so that the above three requirements can be fulfilled, or to develop a new system of ~~induction and~~ <sup>inducible</sup> expression applicable to said microorganism. In the former case, the improvement can be carried out, for example, by site-directed mutagenesis referring to a transcription-translation signal sequence known for the microorganism to be used. In the latter case, the new system can be developed and constructed according to the method of developing the above general inducible-expression systems constructed for Escherichia coli, etc.

Preferred examples of the microorganisms carrying the inducible-expression system include Corynebacterium ammoniagenes strains, etc., which were respectively developed using, as the ~~gene-inducing and expressing~~ <sup>inducible-gene-expression</sup> system, a temperature-inducible plasmid vector which is prepared by ligating the P<sub>L</sub> promoter/cI857 gene carried by pPAC31 which is a vector induced at a high temperature in Escherichia coli with a vector autonomously replicable in Corynebacterium, and pCEX2 capable of regulating the expression by addition of inexpensive acetic acid.

In the present invention, the gene encoding the enzyme capable of synthesizing a purine nucleotide from its precursor may exist in a vector plasmid or may be integrated into the chromosome of a host microorganism, so long as the above three requirements are fulfilled. That is, either a strain carrying

a plasmid containing the gene or a strain in which the gene has been integrated into the chromosome can be used, so long as the expression of said gene can be appropriately regulated.

The inducible-expression plasmid containing the gene  
 5 encoding the enzyme capable of synthesizing a purine nucleotide from its precursor can be introduced into a microorganism which produces the precursor of the purine nucleotide by using the protoplast method, ~~the electric pulse method~~ <sup>electroporation</sup>, the calcium chloride method, and conventional methods  
 10 described in Molecular Cloning, A Laboratory Manual, Second Edition, Cold Spring Harbor Laboratory Press (1989) (hereinafter abbreviated as Molecular Cloning, Second Edition), etc.

For example, when a bacterium belonging to the genus  
 15 Corynebacterium is used as the host microorganism, the protoplast method (Japanese Published Unexamined Patent Application No. 183799/82) and ~~the electric pulse method~~ <sup>electroporation</sup> (Japanese Published Unexamined Patent Application No. 207791/90) are particularly effective. When Escherichia coli  
 20 is used as the host microorganism, the calcium chloride method [J. Mol. Biol., 53, 159 (1970)], etc. can also be employed. <sup>expression of the</sup> The enzyme capable of synthesizing a purine nucleotide from its precursor can be induced and ~~expressed~~ by culturing the thus obtained transformant of the present invention  
 25 carrying the introduced gene encoding the enzyme capable of synthesizing the purine nucleotide from its precursor in an ordinary medium containing carbon sources, nitrogen sources and inorganic substances, and additionally, trace organic nutrients, as may be required, to form and accumulate the  
 30 precursor of the purine nucleotide, and then subjecting the resulting culture to the induction treatment such as heating or addition of acetic acid.

As the carbon source in the medium to be used in the above fermentation step, any carbon source which can be  
 35 assimilated by said microorganism can be used. Examples of suitable carbon sources are carbohydrates such as glucose,

fructose, sucrose, molasses, blackstrap molasses and starch hydrolyzate, alcohols such as ethanol, glycerin and sorbitol, organic acids such as pyruvic acid and lactic acid, and amino acids such as glycine, alanine, glutamic acid and aspartic acid. The preferable concentration thereof is in the range of 5-30%.

Examples of the nitrogen sources include ammonia, various inorganic and organic ammonium salts such as ammonium chloride, ammonium sulfate, ammonium nitrate, ammonium carbonate, ammonium acetate and ammonium phosphate, urea, various amino acids, peptone, NZ amine, meat extract, yeast extract, corn steep liquor, casein hydrolyzate, fish meal and digested matters thereof.

Examples of the inorganic substances include potassium dihydrogenphosphate, dipotassium hydrogenphosphate, magnesium sulfate, magnesium phosphate, sodium chloride, ferrous sulfate, manganese sulfate, zinc sulfate and calcium carbonate.

When the microorganism employed requires particular nutrients such as amino acids, nucleic acids and vitamins for the growth, these substances are added to the medium in appropriate amounts.

Culturing is carried out under aerobic conditions, for example, by shaking culture or spinner culture under aeration. The optimum temperature is usually 26-37°C. The culturing period is usually 1-5 days.

The induction treatment for the expression of the gene encoding the enzyme capable of synthesizing a purine nucleotide from its precursor is carried out under conditions appropriate for the vector used; for example, the vectors mentioned below are preferably treated under the following conditions.

pPAC31 or pBB1: spinner culture under aeration at 37-42°C for 1-24 hours  
pRK248cIts: for 1-24 hours at pH 9  
pPOSEX2: for 1-24 hours in the presence of 50-300 mmol/l

NaCl

pTrc99A: for 1-24 hours in the presence of 0.1-0.5 mmol/l  
IPTG

pAL9181: for 1-24 hours with addition of 0.2% L-  
arabinose

pCEX2: for 1-24 hours with addition of 0.1-2% ammonium  
acetate or sodium acetate

It is preferred to add a surfactant in the reaction step  
to synthesize a purine nucleotide from its precursor.

As the surfactant, those which promote the permeation  
of a purine nucleotide through a cell membrane are preferred.  
Suitable examples are cationic surfactants such as  
polyoxyethylene stearylamine (e.g., Nymeen S-215, NOF  
Corporation), cetyltrimethylammonium bromide, Cation FB and  
Cation F2-40E, anionic surfactants such as sodium oleylamide  
sulfate, Newrex TAB and Rapizole 80, and amphoteric  
surfactants such as polyoxyethylene sorbitan monostearate  
(e.g., Nonion ST221). The surfactant is usually used at a  
concentration of 0.1-50 mg/ml, preferably 1-20 mg/ml.

The reaction in the step to synthesize a purine  
nucleotide from its precursor is carried out at pH 6-8 at  
20-40°C for 1-48 hours.

After the reaction is completed, the purine nucleotide  
formed and accumulated in the reaction mixture can be recovered  
by known methods such as a method comprising removing microbial  
cells and crystallizing the nucleotide by concentration, the  
activated carbon treatment and the ion exchange resin method  
[Isao Endo, et al., Kagakukogakkai (The Society of Chemical  
Engineers, Japan) (ed.), Bioseparation Process Binran  
(Handbook of Bioseparation Process), Kyoritsu Shuppan  
(1996)].

Certain embodiments of the present invention are  
illustrated in the following examples, which are not intended  
to limit the scope of the present invention. The gene  
engineering procedures were carried out according to the  
methods described in Molecular Cloning, Second Edition,

unless otherwise specified.

Example 1 Construction of an XMP-Producing Strain of

Corynebacterium ammoniagenes Carrying the XMP Aminase Gene of Escherichia coli under the Control of P<sub>L</sub> Promoter and Production of GMP by the Strain

(1) Construction of Inducible-Expression Plasmid pLAC857 Capable of Regulating the Expression of the XMP Aminase Gene by the Shift in Temperature

10 A thermal inducible-expression plasmid pLAC857 was constructed from a known plasmid pPLA66 through the following two steps. pPLA66 is a plasmid which expresses XMP aminase at a high level and which was constructed by ligating an XMP aminase gene at a position downstream of the P<sub>L</sub> promoter and  
15 the SD sequence of trpL [Biosci. Biotech. Biochem., 61, 840 (1997)].

A temperature sensitive repressor gene cI857 was inserted into plasmid pPLA66 in the following manner.

20 Plasmid pPLA66 (1 μg) was cleaved with EcoRI (5 units) and BglII (5 units). The cleaved fragments were separated by agarose gel electrophoresis, and a DNA fragment containing the P<sub>L</sub> promoter and the region of the XMP aminase gene (guaA gene) derived from Escherichia coli was recovered from the gel using QIAEXII (QIAGEN CO., LTD.).

25 Plasmid pPAC31 carrying the cI857 gene (WO98/12343) (1 μg) was cleaved with EcoRI (5 units) and BamHI (5 units). The cleaved fragments were separated by agarose gel electrophoresis, and a DNA fragment containing the cI857 gene, an ampicillin resistance gene and the replication origin  
30 derived from Escherichia coli was recovered from the gel.

The DNA fragment containing said gene and the previously prepared DNA fragment containing the guaA gene were ligated by the use of a ligation kit (Takara Shuzo Co., Ltd.).

35 Escherichia coli JM109 (Takara Shuzo Co., Ltd.) was transformed using the ligation mixture and then spread on L agar medium containing 100 μg/ml ampicillin to obtain an

ampicillin-resistant transformant.

A plasmid DNA was extracted from the obtained transformant by the alkali bacteriolysis method.

The plasmid was cleaved with various restriction enzymes and analyzed, whereby it was confirmed that plasmid pLA857 comprising the XMP aminase gene, the <sup>insag</sup> cI857 gene, the ampicillin resistance gene and the replication origin of the plasmid autonomously replicable in Escherichia coli ~~in the region under the control of the P<sub>L</sub> promoter~~ was obtained.

The replication origin of the plasmid autonomously replicable in Corynebacterium was inserted into plasmid pLA857 in the following manner.

Plasmid pLA857 (1  $\mu$ g) was cleaved with PstI (5 units) at the only PstI-cleavage site existing thereon. The cleaved fragment was separated by agarose gel electrophoresis and recovered from the gel, whereby a PstI-cleaved fragment of pLA857 was obtained.

Plasmid vector pCG116 replicable in Corynebacterium ammoniagenes (Japanese Published Unexamined Patent Application No. 265892/89) (1  $\mu$ g) was cleaved with PstI (5 units). After dephosphorylation of the DNA was effected by alkali phosphatase treatment to prevent rebinding, extraction with phenol and precipitation with ethanol were carried out, whereby a PstI-cleaved fragment of pCG116 was obtained.

The above-obtained PstI-cleaved fragment of pLA857 and PstI-cleaved fragment of pCG116 were ligated using the above ligation kit.

Corynebacterium ammoniagenes ATCC 6872 was transformed using 1  $\mu$ g of the DNA obtained by the ligation treatment by means of <sup>electroporation</sup> ~~the electric pulse method~~ [Appl. Microbiol. Biotechnol., 30, 283 (1989)] and then spread on A agar medium [0.5% glucose, 1% peptone, 0.5% meat extract, 0.5% yeast extract, 0.25% sodium chloride, 1.5% agar, 10 mg/l adenine and 10 mg/l guanine (pH 7.2)] containing 100  $\mu$ g/ml spectinomycin.

A plasmid DNA was extracted from the obtained

spectinomycin-resistant transformant by the alkali bacteriolysis method.

The plasmid was cleaved with various restriction enzymes and analyzed, whereby it was confirmed that the obtained  
5 transformant carried plasmid pLAC857 having the desired structure shown in Fig. 1.

Corynebacterium ammoniagenes ATCC 6872/pLAC857 carrying pLAC857 was deposited with the National Institute of Bioscience and Human-Technology, Agency of Industrial  
10 Science and Technology, 1-3, Higashi 1-chome, Tsukuba-shi, Ibaraki-ken, 305-0046 Japan, on February 5, 1999 with accession number FERM BP-6639 under the Budapest Treaty.

(2) Measurement of the XMP Aminase Activity of a Strain  
15 Prepared by Introducing pLAC857 into FERM BP-1261 Strain  
Plasmid pLAC857 was extracted from Corynebacterium ammoniagenes ATCC 6872/pLAC857 (FERM BP-6639) by the alkali bacteriolysis method.

An XMP-producing strain of Corynebacterium  
20 ammoniagenes, FERM BP-1261 (Japanese Patent No. 2618383: adenine-leaky requiring and guanine-requiring), <sup>was</sup> transformed using said plasmid by the above ~~electric pulse~~ <sup>electroporation</sup> ~~method~~.

A plasmid DNA was extracted from the obtained  
25 spectinomycin-resistant transformant by the alkali bacteriolysis method.

The plasmid was cleaved with various restriction enzymes and analyzed, whereby it was confirmed that the obtained transformant carried pLAC857.

30 The XMP-producing strain FERM BP-1261 carrying pLAC857 was cultured by shaking in A medium (a medium prepared by eliminating agar from A agar medium) containing 100  $\mu$ g/ml spectinomycin at 30°C and 37°C, respectively for 24 hours.

After the culturing was completed, cells were obtained  
35 from each culture by centrifugation.

The obtained cells were washed twice with 100 mmol/l

Tris-HCl (pH 7.0) and suspended in 10 ml of the same buffer.

To the resulting suspension was added 10 g of glass beads (Shinmaru Enterprises Co., Ltd., 0.1-0.2  $\phi$ ), followed by disruption using a homogenizer (Nippon Seiki Co., Ltd.) under ice-cooling for 10 minutes.

The obtained suspension was centrifuged (14000 x g) at 4°C for 10 minutes, and the supernatant was recovered as a cell extract.

To 1.15 ml of a reaction mixture [160 mmol/l Tris-HCl (pH 8.6), 12 mmol/l ATP Na<sub>2</sub>·3H<sub>2</sub>O, 16 mmol/l MgSO<sub>4</sub>·7H<sub>2</sub>O and 40 mmol/l (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>] containing the cell extract previously heated to 42°C was added 0.1 ml of 0.3 mol/l XMP to start reaction at 42°C. Fifteen minutes later, 3.9 ml of 3.5% perchloric acid was added to the reaction mixture to stop the reaction.

The reaction mixture was centrifuged at 3000 rpm for 10 minutes, and the absorbance of the supernatant at 290 nm was measured. The specific activity per milligram of protein was calculated taking the activity to form 1  $\mu$ mol of GMP in one minute as one unit (U). The amount of protein was determined using a protein assay kit (BioRad Laboratories).

The results are shown in Table 1. No activity was detected in the cells cultured at 30°C, while the activity was detected in the cells cultured at 37°C. These results indicate that the expression of the XMP aminase gene is under the control of the P<sub>L</sub> promoter in FERM BP-1261 strain carrying pLAC857, and the activity of said enzyme can be regulated by shifting the temperature.

Table 1

Culturing temperature	Specific activity ( $\mu$ mol/min/mg protein)
30°C	Not detected
37°C	0.25

(3) Production of GMP by the XMP-Producing Strain FERM

## BP-1261 Carrying pLAC857

FERM BP-1261 strain carrying pLAC857 was cultured on A agar medium containing 20  $\mu$ g/ml streptomycin at 30°C for 2 days. The obtained cells were inoculated into a 250-ml

5 Erlenmeyer flask containing 60 ml of C seed medium [5% glucose, 1% yeast extract, 1% peptone, 0.25% NaCl, 0.3% urea, 150 mg/l adenine and 150 mg/l guanine (pH 7.2)] containing 20  $\mu$ g/ml streptomycin, followed by shaking culture at 30°C for 24 hours.

The whole of the obtained culture was inoculated into

10 a 2-l fermentor containing 0.94 l of D seed medium [8.8% glucose, 1.7% meat extract, 1.7% peptone, 0.167%  $\text{KH}_2\text{PO}_4$ , 0.167%  $\text{K}_2\text{HPO}_4$ , 0.167%  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ , 333 mg/l adenine, 350 mg/l guanine, 33 mg/l  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ , 17 mg/l  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ , 6.7 mg/l  $\text{MnSO}_4 \cdot 4-6\text{H}_2\text{O}$ , 25 mg/l  $\beta$ -alanine, 33 mg/l L-cysteine, 167  $\mu$ g/l biotin, 1.3 mg/l

15  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  and 8.3 mg/l thiamine (pH 7.2)], followed by culturing with stirring (600 rpm) and aeration (1 l/min) at 30°C for 24 hours, during which the pH was kept at 7.2 with 5.5 mol/l aqueous ammonia.

The obtained culture (120 ml) was inoculated into a 2-l

20 fermentor containing 0.88 l of F fermentation medium [8% glucose, 1.67% orthophosphoric acid, 1.29% KOH, 1.2%  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ , 123 mg/l  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ , 24.6 mg/l  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ , 12.3 mg/l  $\text{MnSO}_4 \cdot 4-6\text{H}_2\text{O}$ , 12.3 mg/l  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ , 18.5 mg/l  $\beta$ -alanine, 24.6 mg/l L-cysteine, 6.2 mg/l nicotinamide, 24.6 mg/l histidine,

25 185  $\mu$ g/l biotin, 2.5 mg/l  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ , 203 mg/l adenine and 10 mg/l guanine (pH 7.2)], followed by culturing with stirring (600 rpm) and aeration (1 l/min) at 28°C for 44 hours, during which the pH was kept at 7.2 with 5.5 mol/l aqueous ammonia.

After the culturing was completed, the amounts of XMP

30 and GMP accumulated in the culture supernatant were determined by HPLC in the following manner.

## Conditions for HPLC analysis

Column: Asahipak GS-320H (Asahi Chemical Industry Co., Ltd.)

35 Eluent: 0.2 mol/l  $\text{NaH}_2\text{PO}_4$  (pH 3.0)

Flow rate: 1 ml/min

Detection: UV 254 nm

The amounts of XMP and GMP accumulated were determined by measuring the absorbance at UV 254 nm and comparing the absorbance with the standard.

5 As the result of HPLC analysis, it was found that XMP was formed and accumulated in an amount of 27.2 g/l, but GMP was not detected.

To induce <sup>+the expression of</sup> ~~and express~~ the XMP aminase gene, the culture broth was heated to 40°C, and kept at the same temperature  
10 with stirring (600 rpm) and aeration (1 l/min) for 6 hours, during which the pH was kept at 7.2 with 5.5 mol/l aqueous ammonia.

To the XMP fermentation broth subjected to the above thermal induction treatment were added 2.5% glucose, 10 g/l  
15 phytic acid, 4.4 g/l  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ , 9.36 g/l  $\text{Na}_2\text{HPO}_4$ , 96.9 mg/l adenine and 10 g/l Nymeen S-215, and the resulting mixture was subjected to reaction with stirring (600 rpm) and aeration (1 l/min) at 40°C for 24 hours, during which the pH was kept at 7.4 with 5.5 mol/l aqueous ammonia.

20 After the reaction was completed, the amount of GMP accumulated in the supernatant of the reaction mixture was determined under the above HPLC analysis conditions. As the result, it was found that GMP was formed and accumulated in an amount of 20.8 g/l.

25 Example 2 Construction of an XMP-Producing Strain of Corynebacterium ammoniagenes Carrying the XMP Aminase Gene of Corynebacterium ammoniagenes under the Control of the Promoter of an Isocitrate Lyase Gene and Production of GMP  
30 by the Strain

(1) Amplification and Cloning of the XMP Aminase Gene by PCR

Isolation of the XMP aminase gene of Corynebacterium ammoniagenes was carried out by PCR based on the nucleotide sequence in the following manner.

35 First, the oligonucleotides shown in SEQ ID NOS: 1 and 2 which are located at both ends of the XMP aminase gene and

which respectively have the cleavage sites for the restriction enzymes AflIII and BamHI were synthesized. The chromosomal DNA of Corynebacterium ammoniagenes ATCC 6872 to be used as the template was prepared according to the method for preparing protoplasts by treating cells cultured in the presence of glycine with lysozyme and achromopeptidase (Japanese Published Unexamined Patent Application No. 225776/94).

The obtained chromosomal DNA (0.1  $\mu$ g), the above oligonucleotides (0.25  $\mu$ mol/l each) as the primers and Taq DNA polymerase (Takara Shuzo Co., Ltd., 2.5 units) were added to 0.1 ml of 10 mmol/l Tris-HCl buffer (pH 8.3) comprising 200  $\mu$ mol/l each of dATP, dCTP, dGTP and dTTP, 50 mmol/l potassium chloride, 1.5 mmol/l magnesium chloride and 0.0001% gelatin, and the resulting mixture was subjected to PCR.

PCR was carried out by repeating 10 times a reaction cycle in which reaction is conducted at 94°C for 90 seconds, at 50°C for 120 seconds and at 72°C for 120 seconds; repeating 10 times a reaction cycle in which reaction is conducted at 94°C for 90 seconds, at 40°C for 120 seconds and at 72°C for 120 seconds; and further repeating 20 times a reaction cycle in which reaction is conducted at 94°C for 90 seconds, at 40°C for 120 seconds and at 72°C for 180 seconds; and then conducting reaction at 72°C for 360 seconds.

The obtained reaction mixture was subjected to agarose gel electrophoresis, whereby the desired DNA fragment of about 1.6 kb was recovered.

Said DNA fragment was cleaved with the restriction enzymes AflIII (5 units) and BamHI (5 units), and a cleaved fragment of about 1.6 kb whose ends were respectively treated with AflIII and BamHI was isolated and recovered by agarose gel electrophoresis.

## (2) Construction of Inducible-Expression Plasmid pGUA2

Capable of Regulating the Expression of the XMP Aminase Gene with a Carbon Source

A plasmid which can regulate the expression of the XMP

aminase gene with a carbon source was constructed in the following manner using inducible-expression vector pCEX2 (Japanese Published Unexamined Patent Application No. 224259/91).

5 pCEX2 is a vector containing the expression-regulating region and the transcription termination signal sequence of the isocitrate lyase gene of Corynebacterium glutamicum, and the expression of an exogenous gene inserted into the multicloning site thereon is suppressed in the presence of  
10 a sugar and is induced in the presence of a non-sugar such as acetic acid.

pCEX2 vector DNA (1  $\mu$ g) was partially cleaved with AflIII (0.5 unit) and then cleaved with BamHI (5 units). Then, a DNA fragment of 7.6 kb containing the expression-regulating  
15 region and the transcription termination signal region of the isocitrate lyase gene, a spectinomycin resistance gene and the replication origin of the plasmid autonomously replicable in Corynebacterium glutamicum was isolated and recovered by agarose gel electrophoresis.

20 Said DNA fragment and the PCR-amplified fragment of the XMP aminase gene obtained in the above Example 2 (1) were ligated to obtain a ligated DNA.

Corynebacterium ammoniagenes ATCC 6872 was transformed using said ligated DNA (1  $\mu$ g) by <sup>electroporation</sup> ~~the electric pulse method~~,  
25 and then spread on A agar medium containing 100  $\mu$ g/ml spectinomycin.

A plasmid DNA was extracted from the obtained spectinomycin-resistant transformant by the alkali bacteriolysis method.

30 The plasmid DNA was cleaved with various restriction enzymes and analyzed, whereby it was confirmed that the obtained transformant carried plasmid pGUA2 having the desired structure shown in Fig. 2.

35 (3) Measurement of the XMP Aminase Activity of a Strain Prepared by Introducing pGUA2 into FERM BP-1261 Strain

Plasmid pGUA2 was extracted from Corynebacterium ammoniagenes ATCC 6872 carrying pGUA2 by the alkali bacteriolysis method.

An XMP-producing strain of Corynebacterium ammoniagenes, FERM BP-1261 (adenine-leaky requiring and guanine-requiring), was transformed using said plasmid by the ~~electric pulse method~~<sup>electroporation</sup>.

A plasmid DNA was extracted from the obtained spectinomycin-resistant transformant by the alkali bacteriolysis method.

The plasmid was cleaved with various restriction enzymes and analyzed, whereby it was confirmed that the transformant carried pGUA2.

The XMP-producing strain FERM BP-1261 carrying pGUA2 was cultured by shaking in two kinds of media, i.e., A medium containing 100  $\mu$ g/ml spectinomycin and a medium prepared by replacing glucose in said medium by ammonium acetate, separately, at 30°C for 24 hours.

Cells were obtained from the resulting cultures to prepare cell extracts in the same manner as in Example 1 (2).

The XMP aminase activity in each of the extracts was measured according to the method described in Example 1 (2).

The results are shown in Table 2.

Only an extremely low level of activity was detected in the cells cultured using glucose as the carbon source, while a high level of activity was detected in the cells cultured using 2% ammonium acetate as the carbon source.

These results indicate that the expression of the XMP aminase gene is under the control of the promoter of the isocitrate lyase gene in FERM BP-1261 carrying pGUA2, and the activity of said enzyme can be regulated by changing the carbon source.

Table 2

Carbon source	Specific activity ( $\mu\text{mol/min/mg protein}$ )
Glucose	0.05
Ammonium acetate	0.38

(4) Production of GMP by the Strain Prepared by Introducing pGUA2 to XMP-Producing Strain FERM BP-1261

5 XMP fermentation was carried out using FERM BP-1261 strain carrying pGUA2 under the same culturing conditions as in Example 1 (3). After the culturing was completed, the amounts of XMP and GMP formed and accumulated in the culture supernatant were determined in the same manner as in Example 10 1 (3).

As the result, the amount of XMP accumulated was found to be 18.4 g/l. GMP was not detected.

After the fermentation was completed, in order to induce ~~the expression of~~ ~~and express~~ the XMP aminase gene, ammonium acetate was added 15 to the fermentation broth to a final concentration of 2%, followed by culturing with stirring (600 rpm) and aeration (1 l/min) for 10 hours, during which the pH was kept at 7.2 with 5.5 mol/l aqueous ammonia.

To the culture subjected to the above induction 20 treatment with ammonium acetate were added 2.5% glucose, 10 g/l phytic acid, 4.4 g/l  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ , 9.36 g/l  $\text{Na}_2\text{HPO}_4$ , 96.9 mg/l adenine and 10 g/l Nymeen S-215, and the resulting mixture was subjected to reaction with stirring (600 rpm) and aeration (1 l/min) at 40°C for 24 hours, during which the pH was kept 25 at 7.4 with 5.5 mol/l aqueous ammonia.

After the reaction was completed, the amount of GMP accumulated in the supernatant of the reaction mixture was determined according to the method described in Example 1 (3).

It was found that GMP was formed and accumulated in an 30 amount of 14.4 g/l in the reaction mixture.

Example 3 Construction of an Inosine-Producing Strain of

Corynebacterium ammoniagenes Carrying the Inosine-Guanosine Kinase Gene of Escherichia coli under the Control of the Promoter of an Isocitrate Lyase Gene and Production of IMP by the Strain

5 (1) Amplification and Cloning of the Inosine-Guanosine Kinase Gene by PCR

Isolation of the inosine-guanosine kinase gene of Escherichia coli was carried out by PCR based on the known nucleotide sequence (W091/08286) in the following manner.

10 The oligonucleotides shown in SEQ ID NOS: 3 and 4 which are located at both ends of the inosine-guanosine kinase gene and which respectively have the cleavage sites for the restriction enzymes AflIII and BamHI were synthesized.

Plasmid pBM2 carried by Escherichia coli HM70/pBM2  
15 (W091/08286) was used as the template of the inosine-guanosine kinase gene.

The above plasmid DNA (0.1  $\mu$ g), the above oligonucleotides (0.25  $\mu$ mol/l each) as the primers and Taq DNA polymerase (Takara Shuzo Co., Ltd., 2.5 units) were added  
20 to 0.1 ml of 10 mmol/l Tris-HCl buffer (pH 8.3) comprising 200  $\mu$ mol/l each of dATP, dCTP, dGTP and dTTP, 50 mmol/l potassium chloride, 1.5 mmol/l magnesium chloride and 0.0001% gelatin, and the resulting mixture was subjected to PCR.

PCR was carried out by repeating 10 times a reaction  
25 cycle in which reaction was conducted at 94°C for 90 seconds, at 50°C for 120 seconds and at 72°C for 120 seconds; repeating 10 times a reaction cycle in which reaction was conducted at 94°C for 90 seconds, at 40°C for 120 seconds and at 72°C for 120 seconds; further repeating 20 times a reaction cycle in  
30 which reaction was conducted at 94°C for 90 seconds, at 40°C for 120 seconds and at 72°C for 180 seconds; and then conducting reaction at 72°C for 360 seconds.

The obtained PCR reaction product was ligated with vector pT-Adv which is a vector for the cloning of a PCR product  
35 (Clontech Co., Ltd.).

Escherichia coli DH5 $\alpha$  was transformed using 1  $\mu$ g of

the DNA obtained by said ligation treatment, and then spread on L agar medium containing 100  $\mu$ g/ml ampicillin.

Plasmid pT-AI was extracted from the obtained ampicillin-resistant transformant by the alkali  
5 bacteriolysis method.

The structure of the plasmid pT-AI was analyzed using various restriction enzymes, whereby it was confirmed that this plasmid contained the inosine-guanosine kinase gene (1.3 kb), an ampicillin resistance gene, a kanamycin resistance  
10 gene and the replication origin of the plasmid autonomously replicable in Escherichia coli.

(2) Construction of Inducible-Expression Plasmid pIGK2  
Capable of Regulating the Expression of the Inosine-  
15 Guanosine Kinase Gene with a Carbon Source

A plasmid which can regulate the expression of the inosine-guanosine kinase gene with a carbon source was constructed in the following manner using inducible-expression vector pCEX2 (Japanese Published Unexamined Patent  
20 Application No. 224259/91).

pCEX2 vector DNA (1  $\mu$ g) was cleaved with KpnI (5 units) and a DNA fragment of 7.6 kb containing the expression-regulating region and the transcription termination signal region of the isocitrate lyase gene, a spectinomycin  
25 resistance gene and the replication origin of the plasmid autonomously replicable in Corynebacterium glutamicum was isolated and recovered by agarose gel electrophoresis.

The plasmid pT-AI containing the inosine-guanosine kinase gene obtained in Example 3 (1) (1  $\mu$ g) was cleaved with  
30 KpnI (5 units), followed by dephosphorylation.

This KpnI-cleaved DNA fragment and the above KpnI-cleaved fragment of pCEX2 were ligated.

Escherichia coli DH5 $\alpha$  was transformed using the obtained ligation mixture, and then spread on L agar medium  
35 containing 100  $\mu$ g/ml ampicillin to obtain an ampicillin-resistant transformant.

A plasmid was extracted from the obtained transformant by the alkali bacteriolysis method.

The plasmid was cleaved with various restriction enzymes and analyzed, whereby it was confirmed that plasmid pIGK2  
5 having the desired structure shown in Fig. 3 was obtained.

Corynebacterium ammoniagenes ATCC 6872 was transformed using this plasmid (1  $\mu$ g) by <sup>electroporation</sup> ~~the electric pulse method~~ and then spread on A agar medium containing 100  $\mu$ g/ml spectinomycin.

10 A plasmid DNA was extracted from the obtained spectinomycin-resistant transformant by the alkali bacteriolysis method and it was confirmed that the transformant carried pIGK2.

Corynebacterium ammoniagenes ATCC 6872/pIGK2 carrying  
15 pIGK2 was deposited with the National Institute of Bioscience and Human-Technology, Agency of Industrial Science and Technology, 1-3, Higashi 1-chome, Tsukuba-shi, Ibaraki-ken, 305-0046 Japan, on February 5, 1999 with accession number FERM BP-6638 under the Budapest Treaty.

20 (3) Measurement of the Inosine-Guanosine Kinase Activity of a Strain Prepared by Introducing pIGK2 into FERM BP-2217 Strain

Plasmid pIGK2 was extracted from Corynebacterium  
25 ammoniagenes ATCC 6872/pIGK2 (FERM BP-6638) by the alkali bacteriolysis method.

An inosine-producing strain of Corynebacterium  
ammoniagenes, FERM BP-2217 (Japanese Patent No. 2578496: adenine-leaky requiring and guanine-requiring), was  
30 transformed using said plasmid by <sup>electroporation</sup> ~~the electric pulse method~~.

A plasmid DNA was extracted from the obtained spectinomycin-resistant transformant by the alkali bacteriolysis method.

The plasmid was cleaved with various restriction enzymes  
35 and analyzed, whereby it was confirmed that the obtained transformant carried pIGK2.

The inosine-producing strain FERM BP-2217 carrying pIGK2 was cultured in two kinds of media, i.e., A medium containing 100  $\mu$ g/ml spectinomycin and a medium prepared by replacing glucose in said medium by ammonium acetate, separately, at 30°C for 24 hours.

Cells were obtained from the resulting cultures to prepare cell extracts according to the method described in Example 1 (2).

The inosine-guanosine kinase activity in each of the extracts was measured in the following manner.

To 0.1 ml of a reaction mixture [100 mmol/l HEPES buffer (pH 7.2), 10 mmol/l  $\text{MgSO}_4$ , 50 mmol/l KCl, 1 mmol/l ATP and 1 mmol/l inosine] previously heated to 30°C was added 0.01 ml of the cell extract, followed by reaction at 30°C for about 30 minutes.

During the reaction, the reaction mixture was sampled at intervals and the samples taken were diluted 20-fold with 0.2 mol/l  $\text{NaH}_2\text{PO}_4$  (adjusted to pH 2.6 with  $\text{H}_3\text{PO}_4$ ) to stop the reaction.

The amounts of inosine and IMP in the diluted samples were determined by HPLC analysis.

Conditions for HPLC analysis

Column: Asahipak GS-320H (Asahi Chemical Industry Co., Ltd.)

Eluent: 0.2 mol/l  $\text{NaH}_2\text{PO}_4$  (pH 2.6)

Flow rate: 1 ml/min

Detection: UV 254 nm

The amounts of inosine and IMP accumulated were determined by measuring the absorbance at UV 254 nm and comparing the absorbance with the standard. The specific activity per milligram of protein was calculated taking the activity to form 1  $\mu$ mol of IMP in one minute as one unit (U).

The amount of protein was determined using a protein assay kit (BioRad Laboratories).

The results are shown in Table 3. Only an extremely low level of activity was detected in the cells cultured using

glucose as the carbon source, while a high level of activity was detected in the cells cultured using 2% ammonium acetate as the carbon source. These results indicate that the expression of the inosine-guanosine kinase gene is under the control of the promoter of the isocitrate lyase gene in FERM BP-2217 carrying pIGK2, and the activity of said enzyme can be regulated by changing the carbon source.

Table 3

Carbon source	Specific activity ( $\mu\text{mol}/\text{min}/\text{mg}$ protein)
Glucose	0.02
Ammonium acetate	0.34

10

#### (4) Production of IMP by the Inosine-Producing Strain FERM BP-2217 Carrying pIGK2

FERM BP-2217 strain carrying pIGK2 was cultured on A agar medium containing 20  $\mu\text{g}/\text{ml}$  streptomycin at 30°C for 2 days.

After the culturing was completed, the obtained cells were inoculated into a 250-ml Erlenmeyer flask containing 60 ml of CI seed medium [5% glucose, 1% yeast extract, 1% peptone, 0.25% NaCl, 0.25% urea, 300 mg/l adenine and 100 mg/l guanine (pH 7.2)] containing 20  $\mu\text{g}/\text{ml}$  streptomycin, followed by shaking culture at 30°C for 24 hours.

The whole of the obtained culture was inoculated into a 2-l fermentor containing 0.94 l of DI seed medium [7% glucose, 1% meat extract, 1% peptone, 0.1%  $\text{KH}_2\text{PO}_4$ , 0.1%  $\text{K}_2\text{HPO}_4$ , 0.1%  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ , 300 mg/l adenine, 300 mg/l guanine, 10 mg/l  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ , 10 mg/l  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ , 10 mg/l  $\text{MnSO}_4 \cdot 4-6\text{H}_2\text{O}$ , 16 mg/l  $\beta$ -alanine, 20 mg/l L-cysteine, 30  $\mu\text{g}/\text{l}$  biotin, 2 mg/l  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  and 6 mg/l thiamine (pH 7.2)], followed by culturing with stirring (600 rpm) and aeration (1 l/min) at 30°C for 24 hours, during which the pH was kept at 7.2 with 5.5 mol/l aqueous ammonia.

The obtained culture (120 ml) was inoculated into a 2-l

fermentor containing 0.88 l of FI fermentation medium [8% glucose, 2.07% CSL, 0.21%  $\text{KH}_2\text{PO}_4$ , 0.21%  $\text{K}_2\text{HPO}_4$ , 0.43%  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ , 105 mg/l  $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ , 10.4 mg/l  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ , 20.7 mg/l  $\text{MnSO}_4 \cdot 4-6\text{H}_2\text{O}$ , 5.2 mg/l  $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ , 10.4 mg/l calcium

5 pantothenate, 20.7 mg/l L-cysteine, 5.2 mg/l nicotinic acid, 93.8  $\mu\text{g/l}$  biotin, 0.51 mg/l  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  and 313 mg/l adenine (pH 7.2)], followed by culturing with stirring (600 rpm) and aeration (1 l/min) at 28°C for 44 hours, during which the pH was kept at 7.2 with 5.5 mol/l aqueous ammonia.

10 After the culturing was completed, the amounts of inosine and IMP formed and accumulated in the culture supernatant were determined according to the method described in Example 3 (3).

The amount of inosine formed and accumulated in the culture supernatant was 23.1 g/l and IMP was not detected.

15 After the culturing was completed, in order to induce ~~the expression of~~ ~~and express~~ the inosine-guanosine kinase gene, ammonium acetate was added to the obtained culture to a final concentration of 2%, followed by culturing with stirring (600 rpm) and aeration (1 l/min) for 10 hours, during which the pH was kept at 7.2 with 5.5 mol/l aqueous ammonia.

20 To the obtained culture were added 2.5% glucose, 10 g/l phytic acid, 4.4 g/l  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ , 9.36 g/l  $\text{Na}_2\text{HPO}_4$ , 96.9 mg/l adenine and 10 g/l Nymeen S-215, and the resulting mixture was subjected to reaction with stirring (600 rpm) and aeration (1 l/min) at 40°C for 24 hours, during which the pH was kept at 7.4 with 5.5 mol/l aqueous ammonia.

25 After the reaction was completed, the amount of IMP accumulated in the supernatant of the reaction mixture was determined according to the method described in Example 3 (3).

30 It was found that IMP was formed and accumulated in an amount of 37.7 g/l in the reaction mixture.

## Sequence Listing

&lt;110&gt; Yutaka TAKANO

Masato IKEDA

5 Tatsuro FUJIO

&lt;120&gt; Process for producing purine nucleotide

&lt;130&gt; 11183

10

&lt;150&gt; JP99/29783

&lt;151&gt; 1999-02-08

&lt;160&gt; 4

15

&lt;210&gt; 1

&lt;211&gt; 47

&lt;212&gt; DNA

&lt;213&gt; Artificial Sequence

20

&lt;223&gt; Synthetic DNA

&lt;400&gt; 1

ccgcggccta aggaagttac ctgtgtgact caacctgcaa caactcc 47

25

&lt;210&gt; 2

&lt;211&gt; 40

&lt;212&gt; DNA

&lt;213&gt; Artificial Sequence

30

&lt;223&gt; Synthetic DNA

&lt;400&gt; 2

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&lt;210&gt; 3

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5 <223> Synthetic DNA

<400> 3

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10 <210> 4

<211> 40

<212> DNA

<213> Artificial Sequence

15 <223> Synthetic DNA

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